METEOROLOGY AND WAR-FLYING.[1]

Three lectures given at the United States Army School of Military Aeronautics, Massachusetts Institute of Technology.

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OUTLINE.

INTRODUCTION.

There is no need of emphasizing the importance of a knowledge of meteorology on the part of those whose business it is to sail through the ocean of air. This ocean has its tides, its currents, its waves. It is beginning to be charted, but only just beginning.[2] A seaman navigates his vessel in all sorts of weather, but skill in local weather forecasting, and a practical knowledge of the laws of storms, are invaluable in making possible a speedier, safer, and more successful voyage. Similarly, the navigator of the air, though war service often involves flying under atmospheric conditions far from favorable, inevitably finds, sooner or later, that the more he knows about the air which he is navigating, the better equipped he is as a fighter, as a photographer, or on reconnaissance work. At critical times, meteorological knowledge has time and again proved its practical value to those who navigate the air. Meteorologists are waiting to put all that they know at the service of the men who fly. And the men who fly will, in their turn, advance meteorological science by means of the facts which their own practical experience in the air will impress upon their minds. He who knows most about practical meteorology is the best equipped for service in the air. He is, therefore, the most likely, other things being equal, to do his country the greatest service.

The aviator who is sent to a foreign war zone may wisely, if time allows, inform himself regarding the climate of the region in which he is to fly. It is a practical help to know about the prevailing winds, the number of stormy days, the distribution and amount of precipitation, the occurrence of gales, the general character of the weather, and the like. Such data are easily obtainable from the usual climatic summaries.[3] A convenient recent summary of French data is printed in the MONTHLY WEATHER REVIEW, October, 1917, pp. 487–496, and reprinted in the November or December, 1917, issues of the monthly "Climatological data" issued at section centers.

Climate is the average, and is made up of the individual, day-by-day atmospheric conditions which we call weather. A climatic summary for any given month, or season, shows the *average* or *normal* conditions. It by no means necessarily shows what any particular month or season is to be. There is no way, as yet, of knowing that in advance. Obviously, some knowledge of the weather which he is to experience to-day and to-morrow, is of immediate and essential importance to the aviator. He is helped by knowing something of the general climatic conditions of his field of operations. But he wants, much more, to know what weather to expect within the next few hours. In other words, he wants to know "not what *may* be but what *will* be." [4] He needs regular daily weather forecasts. And these require an organized system of meteorological observations made by trained observers, collected by telegraph, and charted. With such an organized military meteorological field service the aviator is not himself directly concerned. The forecasts are supplied to him. He can, however, help himself a great deal if he has a good "working" knowledge of daily weather maps[5]; if he knows something of the relations and movements of weather types, and is sufficiently familiar with weather prognostics to be able to make his own rough-and-ready forecasts in case he can not receive the official forecast, or wishes to interpolate his own prediction at a time when no regular forecast is issued.

Details regarding the field weather service of the Allies are confidential, but information which has been given to the public shows that the meteorological organization is widespread and effective. So far as Great Britain is concerned, we know that a separate unit of the Royal Engineers has been created for meteorological service in the field. The service in France has been under the command of Maj. Ernest Gold, and that in the eastern Mediterranean under Capt. E. M. Wedderburn. With him is, or was, Lieut. E. Kidson of New Zealand, who has distinguished himself as magnetician in the service of the Carnegie Institution of Washington. Maj. H. G. Lyons, R. E., formerly director general of the Egyptian Survey Department, took charge of the Mediterranean area in May, 1915. A professor of meteorology to the Royal Flying Corps has been appointed, the appointee being Lieut. (now Maj.) G. I. Taylor, Royal Flying Corps, who was previously Schuster Reader in Meteorology. The special meteorological service organized by the Italian Army has published several bulletins dealing with the military relations of meteorology and climatology. Among the subjects so far considered are the climates of the districts in the war zone and details regarding avalanches, with lists of places specially subject to them.

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[1] GENERAL REFERENCES.

Great Britain. Royal Flying Corps. Training manual.

Shaw, Sir Napier. The weather map. Meteorological Office, London, 1917. 3d issue. (M. O. no. 2251.)

In addition to these sources of information and other references given later, the following publications may prove useful:

Linke, Franz. Aeronautische Meteorologie, Pt. I and II. Frankfurt a/M., 1911. 173 and 126 p. 8°. (Deals chiefly with balloons and is somewhat out of date, but still useful.)

Humphreys, W. J. Physics of the Atmosphere. Jour. Franklin Instit., March, 1913. Specially pp. 233–241.

McAdie, Alex. G. Principles of Aerography. Chicago, 1917. 8°. (The most recent book on the subject; summarizes the latest advances in meteorology, lays special emphasis on modern methods of dealing with the problems of the atmosphere and on the practical application of the available knowledge.)

Idem. Aviation and aerography. Aviat. and aeronaut. engin., Aug. 15, 1916, 1: 8–11; also in Sci. amer. suppl., June 2, 1917, No. 2161, pp. 341–342.

Idem. Aerography: the science of the structure of the atmosphere. Geogr. rev., New York, April, 1916, 1: 265–273.

Rotch, A. Lawrence. Conquest of the air. New York, 1909. 8°.

Sounding the ocean of air. 1900. 174 p. sm. 8°.

[2] *Rotch, A. Lawrence, & Palmer, Andrew H.* Charts of the atmosphere for aeronauts and aviators. New York, 1911.

[This is a pioneer publication on its subject. It presents, in a practical form, some of the results obtained at Blue Hill Observatory, Mass., during 20 years of observation. The charts are "the first of their kind adapted to the use of airmen". They relate chiefly to Blue Hill, but apply also to larger portions of the United States. The final chart shows the best aerial routes across the North Atlantic Ocean in summer.]

[3] The standard book on climate is *J. von Hann:* Handbuch der Klimatologie. 3d ed., Stuttgart, 1908–1911. 3 v. 8°.

On the western front the winds are prevailingly from the western quarter. Hence the German machines have an advantage in case of engine trouble. An Allied airplane will be likely to have "its gliding path so shortened that the aviator will mostly have to land in 'No Man's Land' if he does not come down within the enemy lines." F. W. Lanchester, the "London Times" correspondent on the western front, reports that "fighting nearly always drifts over the enemy's territory, and that the Germans habitually endeavor to draw our men farther over their own ground, where even a small mishap may prevent them, against the adverse winds, from regaining their own lines."

[4] Sir Napier Shaw.

[5] See section on *Weather Forecasting* p. 599, below.

The United States Signal Corps, with the cooperation of the Weather Bureau through the National Research Council, has also organized an extensive meteorological service in France. Maj. (formerly Supervising Forecaster) E. H. Bowie has charge of the forecasting, and has associated with him Lieut. R. H. Weightman. Maj. (formerly Prof.) Wm. R. Blair has charge of the field observations, specially the aerological observations with pilot and sounding balloons for the benefit of aviators and artillerists. He will have associated with him Capts. A. H. Thiessen and W. G. Reed, and a considerable number of other Weather Bureau employees who are now attached to this important military unit. A somewhat similar service, in the interest of naval meteorology, is being organized by Senior Lieut. W. F. Reed, jr., U. S. N., with whom likewise are associated a number of Weather Bureau men, forming a nucleus for the development of a more extended service of a meteorological nature.

THE ATMOSPHERE.

General.

With the composition of the atmosphere in which he flies, the aviator has no particular concern. He may be interested in the nitrogen as a source of nitric acid and of nitrates, the chemical constituents of gunpowder and of fertilizers. The water vapor becomes critical when condensed into clouds or rain. The oxygen plays an important part in engine performance, but its amount becomes of direct concern to the pilot only when, at great altitudes, insufficient oxygenation of the blood may lead to temporary physiological disturbances. It is the physical conditions of the atmosphere, notably temperature, pressure, air movement, which are of immediate interest in aviation.

Temperatures in the free air.[6]

In the average, the temperature of the free air falls with height. The mean rate of decrease is 1°F. in 300 feet of ascent (10°F. [5.56° C.] per km.). Therefore, if the temperature at sealevel happened to be 50°F., the freezing point (32°F.) might be expected at about 1 mile above the surface.[7] At a height of about 5 miles, the freezing point of mercury (−40°F.) is reached.[8] Temperatures between 0° and −40°F., varying with the season and with the weather type, may be expected at the present highest flying levels. There is a seasonal difference of temperature between summer and winter in the free air, but it is less than at the earth's surface. At about 6 miles the mean winter temperature is in the vicinity of −70°F. (−56.67°C.), and that of summer, −60°F. (−51.11°C.). This decrease in temperature continues up to the level of the highest clouds (about 6 miles = 10 kms.), beyond which, so far as observations have extended, there seems to be no further decrease of temperature with height. There may even be a slight increase. This upper layer (*stratosphere*) is beyond flying limits. The lower layer (*troposphere*) is the one with which we are concerned.

Near the earth's surface (i. e., within 2 miles or so), the rate of change of temperature vertically is very irregular. It may be more, or less, rapid that 1° F. in 300 feet; there may be no change, or there may even be a rise of temperature with height. On calm, clear nights, in the colder months especially, it very often happens that the temperature distinctly rises for a time with increasing elevation. There is then a warmer layer of air over a colder one. This condition is known as an "inversion of temperature." It is associated with cool or cold, more or less stagnant lower air; is often accompanied by a fog, and quickly disappears if a wind springs up, or when the morning sun is strong enough to warm the earth's surface and the lower air. When flying up through such an "inversion," the aviator will find the temperature rising at first, and then falling at something like the usual rate. Above the stagnant lower air, also, the machine will enter moving currents. Inversions are not limited to the earth's surface. They are frequently found aloft, especially above cloud layers. The kind and amount of change of temperature vertically is an indication of atmospheric stability or instability. When the temperature decreases rapidly with increasing altitude, the air is unstable, and vertical currents will occur. When the temperature increases with ascent, the air is stable, and there is little vertical movement as far up as the inversion extends. In flying through successive layers of air, many different temperature conditions may be met with, but on the average, as stated above, the temperature falls at a rate of 1° in 300 feet.

Pressure.

For several reasons, pressure is the most important meteorological element in aviation. (1) Observations of pressure make the determination of altitude possible; (2) the resistance of the air and the performance of the engine to some extent depend on pressure;[9] (3) pressure and its changes control air movements and, through these, the other weather elements, such as temperature, humidity, cloudiness, rainfall. The ocean of air and the ocean of water are alike in many ways. The deeper the diver descends below the surface of the water, the greater the pressure he has to endure. The deeper man is submerged in the atmosphere, i. e., the more air there is over him, the greater the weight or pressure of that air. The decrease of pressure aloft, with decreasing depth of immersion in the ocean of air, may produce certain physiological effects which may, usually temporarily, cause discomfort or perhaps even disability.[10] Air, like water, adjusts itself to differences of level; "seeks its own level." Moving air (wind) is making such an adjustment. Atmospheric pressure over the higher latitudes of the earth's surface usually changes considerably

[6] Information regarding the methods of obtaining temperatures in the free air may be found in the newer text books on meteorology.

[7] 50° − 32° = 18°; 300 × 18 = 5,400 feet.

[8] Many hundreds of observations in central Europe, made with ballons-sondes and manned balloons, have given the following mean temperatures at various altitudes in the free air, up to the present highest flying levels:

Altitude.		Temperature.	
Miles.	*Kms.*	*°F.*	*°C.*
(0.0)	(0)	(48 9)	(9 39)
0.6	1	41 0	5.00
1.2	2	32 9	0.50
1.9	3	24 8	− 4 00
2.5	4	15 4	− 9 22
3.1	5	4 3	−15 39
3.7	6	− 7.6	−22.00
4.3	7	−20 2	−29.00
5.0	8	−33.2	−36.22

In converting statute miles into kilometers, and kilometers into statute miles, the following simple rules, which give results sufficiently accurate for all ordinary purposes and were suggested by Prof. J. B. Woodworth, of Harvard University, will be found useful.

A. To convert statute miles into kilometers:

To the number of miles add $\frac{1}{2}$, $\frac{1}{10}$, and $\frac{1}{100}$ of that number.

B. To convert kilometers into statute miles:

To $\frac{1}{2}$ of the number of kilometers, add $\frac{1}{8}$ of that number. If, for every 1,000 miles, 4 be subtracted from the final result, still greater accuracy is secured.

[9] The power of the engine depends on the amount of air, and on the corresponding amount of fuel, taken into the cylinders at each explosion i. e., on the density of the air. *This is dependent on the pressure and also on the temperature. Under ordinary* conditions when the pressure is higher, or the temperature lower, the performance of the engine is better. When the pressure is lower, or the temperature higher, the tendency is the opposite. On a hot day the performance near the surface would be somewhat like that at a higher altitude on a normal day. When the sealevel pressure is low, the engine works under conditions similar to those somewhat above the surface on a day with normal pressure. There is, however, compensation for the decrease in the power of the engine at great altitudes in the lessened resistance of the air when the density is lessened. And there comes in also the effect of the cold at great altitudes in causing poor ignition.

[10] Information on this subject may be found in numerous writings on mountain climbing and on aeronautics: also in medical works. See further *J. Hann:* Handbook of climatology, v. 1, 2d ed., translated by *R. De C. Ward*, New York, 1903. pp. 224–230.

from day to day. In the construction of weather maps for the purposes of weather forecasting, the meteorologist must know the pressure conditions over a large area. In flying, it is the pressure which gives the aviator his altitude.

The mercurial barometer is the standard instrument for determining pressure in all accurate meteorological work. It is, however, wholly unsuited for use in flying. It is heavy, difficult to carry, very delicate, and its readings require many corrections.[11] The height of its mercury column (in inches or millimeters) indicates the pressure of the air. The aneroid ("without fluid") barometer is portable, is not so easily broken, and does not require so many complicated corrections. Hence it is a much more convenient instrument, but is less accurate. An increase in pressure compresses the corrugated top of an elastic metallic vacuum box, and a decrease in pressure allows the box to recover again.[12] A spring helps the action, and a simple system of arms and levers magnifies and changes the vertical movements of the box cover into a circular movement of a needle around a dial. This dial is graduated into inches and tenths of inches, or into millimeters, by comparison with a standard mercurial barometer. Aneroids should frequently be compared with mercurial barometers in order to insure the greatest possible accuracy. They are more reliable in showing changes of pressure than absolute pressures. They need careful handling; should if possible be kept from extreme and sudden temperature changes and from all violent knocks or jars. As the mechanism lags behind the pressure-change because of unavoidable defects of elasticity, it follows that during a rapid ascent the readings are likely to be too high, and during a rapid descent they are likely to be too low. This would give too low an altitude in ascending and too high an altitude in descending. It is obvious that this lag should be absolutely the minimum obtainable.

Aneroids may be made self-recording, and are then known as barographs.[13] The changes in pressure are recorded on a sheet of paper wound around a cylinder driven by clockwork inside. Barographs are made of various sizes, even down to those which are small enough to be carried in the pocket.

It is in the determination of altitudes that barometers have their chief use in aviation. If the difference in pressure between two places, one higher than the other, be known, the difference in the elevation of the two stations may be determined. The pressure at the higher station will be less because there is less weight of air upon the barometer there. Between the two stations there is a column of air whose height corresponds to the difference in pressure at these stations. If the height of this column be known, the elevation of the upper station above the lower is known. Unfortunately for easy memorizing, the heights of the air columns corresponding to given pressure-differences vary, depending upon the density of the air, upon the temperature, pressure, humidity, etc. Formulæ are available for use in determining the differences of height where the various required elements are known. Published tables, however, make the solution of the problem much simpler, and are widely used.[14] When aneroid barometers are provided with a scale to show altitudes as well as pressures, a certain length of air column, at a selected mean temperature and mean pressure, is taken as the standard. In other words, it is *assumed* that for a pressure change of, say, 1 inch, or 25 mm., the corresponding height of air column is so many feet, or meters. Clearly, whenever the pressure or temperature, or both, at the time of any observation differ from the selected mean, there will be an error in the resulting altitude as indicated on the altitude scale. This error may amount to several per cent. The aviator, however, does not have to know his altitude with absolute exactness. In the newest aneroids the errors are being gradually reduced.

For ordinary use in aviation, the "altimeter" replaces the aneroid barometer. The "altimeter" is an aneroid graduated to show height instead of pressure. It should be sensitive, and have an open scale, easily read. A good "altimeter," if properly adjusted, is sufficiently accurate for all ordinary flying purposes. No determination of altitude, it may be worth noting here, can be really accurate unless there are two *simultaneous* readings of pressure, one at the lower station, whose altitude above sealevel is known, and the other at the upper station, or in an aeroplane. In addition, the temperature of the intervening air column should be known. This is usually taken to be the mean of the temperatures at the upper and lower stations, observed simultaneously. The altitude of an aeroplane as indicated by aneroid, depends on the difference of pressure between the height at which the machine happens to be and the pressure at which it left the ground. As the surface pressures may very likely vary during a flight, it is easy to see that the supposed altitude of the machine may differ appreciably from its actual altitude provided these pressure changes have been considerable. This error can not be provided for under ordinary conditions of war flying. If the instrument be carefully adjusted to the pressure and altitude at the starting point, the readings may be assumed to be substantially accurate.[15]

In addition to the direct use of barometers in the determination of altitude, they are also important to the aviator in showing the distribution of pressure over the earth's surface. It is this which determines wind movement. When barometer readings are reduced to sealevel, and plotted on a map, differences of pressure are seen to exist. Places that have the same (sealevel) pressure are joined by lines known as *isobars* (equal pressure). Isobars are essentially like the contour lines on a topographic map. On the daily weather maps of the United States and Canada isobars are drawn for every 0.10 inch.[16] Any weather map [17] shows the existence of regions where the pressures are relatively low. These areas are surrounded by more or less circular or oval isobars; are marked LOW, and are depressions in the atmospheric topography. There are other areas of relatively high pressure; also more or less circular or oval in shape, and marked HIGH. These are elevations in the topography of the atmosphere. A weather map is to be regarded essentially as a contour map. It shows elevations and depressions; hills and hollows. If there were no disturbing causes, the pressure at sealevel would everywhere be the same; the atmosphere would be at rest.

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[11] For information see *Charles F. Marvin:* Barometers and the measurement of atmospheric pressure. Circular F, Instrument Division, U. S. Weather Bureau.

[12] Several vacuum boxes may be used.

[13] *See* "Barometers and the Measurement of Atmospheric Pressure."

[14] See e. g., Smithsonian Meteorological Tables, or "Barometers and the Measurement of Atmospheric Pressure."

[15] In case the "altimeter" becomes broken, and an ordinary aneroid, graduated only for pressures, is available, it may be of help in an emergency to know that about 1000 feet of altitude roughly correspond to about 1 inch of pressure-decrease. This is a very crude and therefore inaccurate means of judging heights, but it may serve for lack of something better.

[16] On the English maps isobars are drawn for intervals of 5 mbars. (millibars). One thousand millibars equal 1 bar. The bar is equal to the pressure of 29 531 inches (750.1 mms.) of mercury at 32° F. (0° C.) and at latitude 45°. It is equivalent to a pressure of 1 megadyne per square centimeter, i. e., to 1,000,000 dynes *per square centimeter. Hence a millibar is equivalent to 1,000 dynes per square centimeter.*

[17] See later section on *Weather Forecasting*, p. 599.

A glance at any weather map will show that the distances between the isobars vary. As the pressure difference between any two adjacent isobars is always the same (0.10 inch or 5 mbars.), it follows that where the isobars are close together the pressure is observed to rise or fall rapidly as one crosses them, and where they are far apart the rise or fall is slow.[18] The *barometric* or *pressure gradient* is steep or gentle; strong or weak. In other words, just as crowded contour lines show steeper slopes on a topographic map, so crowded isobars on a weather map show steeper slopes of the isobaric surfaces in the atmosphere. And as water on the earth's surface flows down hill slopes and into hollows, so air, obeying a similar impulse, tends to flow away from areas of higher pressure and toward areas of lower pressure. If left to itself, the wind would naturally blow directly down the atmospheric slopes along the shortest path from one isobar across to the next lower isobar, and so on until it reached the bottom of the slope (LOW). It would follow the line of most rapid pressure decrease, crossing the successive isobars at right angles. The winds would therefore blow directly out and away from centers of higher pressure, and directly into centers of lower pressure. They would be radial.

The wind in relation to pressures at the earth's surface.

The winds are unable to follow the line of the pressure gradient. The fact that the earth rotates causes winds in the Northern Hemisphere to be deflected to the right of a direct path, i. e., the tendency is for them to blow parallel with the isobars rather than directly across them.[19] Friction comes into play and resists the tendency of the wind to blow more and more to the right. The differences of pressure produce the slope (gradient) on which the air moves. The rotation of the earth deflects the wind (to the right in the Northern Hemisphere). Friction opposes varying resistances. The resultant surface wind directions are neither directly down the slope, nor parallel with the isobars, but somewhere between the two. Around an area of low pressure in the Northern Hemisphere the wind therefore blows in and around to the left. The system is an inward spiral, counter-clockwise, and is known as a *cyclonic* wind system. In the case of a similarly situated high-pressure area the winds blow out, and around to the right. This is an outward clockwise spiral—an *anticyclonic* wind system.[20]

So well defined are these systems of winds that one of the best-known laws of meteorology has been based upon them. *Stand with your back to the wind (in the Northern Hemisphere) and the pressure will be lower on your left hand than on your right.* This is Buys-Ballot's Law, and its formulation dates from 1857. It is a necessary consequence of the earth's rotation. Naturally, irregularities of pressure distribution, the varying effects of topography, and other causes, often cause local winds to depart from the general rule. If the minuter details of pressure could be observed and charted, most of the apparent "exceptions" would probably be seen to be in agreement with the rule.

Regarding wind velocity, it is easily inferred from what has been said above that where the isobars on a weather map are close together, there the winds will have higher velocities, and where the isobars are far apart, there the winds will be gentle. For surface winds, which are greatly affected by friction, no satisfactory definite rule can be given for a relation between wind velocity and pressure gradient. At moderate altitudes, however, it is possible, within certain limitations, to calculate both the direction and the velocity of the air currents.[21] One thing is very clear. Very small pressure differences can produce high winds.

Wind velocity may be estimated, and then expressed according to an accepted scale, such as the well-known Beaufort Scale dating from the early part of the last century. The equivalents of the numbers of the Beaufort Scale, in miles an hour and in pressure per square foot, have been determined.[22] On American weather maps, wind velocity is given in miles an hour in the printed table. On English maps, the number of barbs on the wind arrows indicate the velocity according to the Beaufort Scale. On the French maps the barbs indicate the velocity according to a scale of 4, but the tabulated observations use a scale of 9.

In the United States meteorologists commonly measure wind velocity by means of the Robinson cup anemometer.[23] This instrument is unsatisfactory for aviation purposes because it does not indicate the gustiness of the wind, which is usually much more important than mean velocity. A better instrument for this purpose is the Dines pressure-tube anemometer, much used in England. In this the varying wind pressure and suction raise or lower a float whose changes of level are recorded on a chart wrapped around a drum driven by clockwork.[24]

Even the steadiest wind is gusty. Observations with self-recording anemometers of the Dines and other patterns, show that gustiness varies greatly with different wind directions and in different places.[25] The Dines anemometer may also be adapted to show wind direction by providing it with a wind vane.

In war flying aviators have no occasion to make their own instrumental observations of any weather element. Such data are supplied by the military field weather services. It is, however, desirable that each aviator should have some knowledge of the essential meteorological instruments, so that if necessary he may read them himself.

AIR CURRENTS ABOVE THE SURFACE IN RELATION TO AVIATION.

There are no "holes" in the air. The term is misleading and inaccurate. It conveys the idea of a vacuum or of a partial vacuum; of a local deficiency of air which does not exist. The idea of "holes," of "pockets," and of "dead spaces" comes from the fact that there are often sudden changes in the relation of the aeroplane to the air current by which it happens, at the moment, to be supported. Such a failure in adjustment may be caused by a sudden change in the direction or in the velocity of the general currents in which the machine is flying, by encountering ascending or descending air movements, by flying across atmospheric waves, and in other ways. Horizontal gusts and lulls produce a temporary change

[18] It seems better to reserve the expression "pressure change" for the change in pressure at one and the same point within a stated interval of time, e. g., "the 24-hours pressure change." United States forecasters map the 24- and 12-hour pressure changes and use them constantly in forecasting.—C. A., jr.

[19] *Ferrel's Law:* The amount of deflection depends upon the velocity of the wind and upon the latitude.

[20] These whirls develop centrifugal components which come into play in modifying the wind directions and velocities. In the case of a LOW, the effect of the gradient is balanced against the effects due to the earth's rotation and the centrifugal component of the whirl. In a HIGH, the gradient and the centrifugal component of the whirl are balanced against the earth's rotation.

[21] See later under *Forecasts of Wind Direction and Velocity Aloft*, p. 599.

[22] See e. g., *W. N. Shaw: Forecasting weather.* London, 1911. pp 30-31.

[23] *See* Instructions for the installation and maintenance of wind measuring and recording apparatus, Circular D, Instrument Division, U. S. Weather Bureau.

[24] A description of this instrument will be found in the Observer's Handbook of the British Meteorological Office.

[25] The *fluctuation of the wind* is the difference between the average maximum velocity reached in the gusts and the average minimum velocity in the lulls. The ratio of the fluctuation to the mean velocity is the *gustiness*.

in the pressure of the air against the machine—i. e., in the velocity of the aeroplane *through the air*, causing a momentary change in the lift. The resulting effects depend on whether the aeroplane is moving with or against the wind and on its relative velocity with respect to this wind. If the machine happens to fall rapidly, there is apparently a "hole." Again, when the angle at which the wind strikes the machine changes, there is also a change in the lifting power. If the angle becomes more upward, the machine will rise; if more downward, it will fall. Should a machine suddenly come into a current of air having exactly the same direction and velocity as itself, it would be in a "dead space." Under conditions of active vertical air movements an aviator may pass rapidly from an ascending to a descending current. His machine will then descend. A descending movement does not, however, continue until it strikes the ground vertically. It must obviously become more and more horizontal as it nears the surface. Again, a pilot may find his machine just on the dividing line between an ascending and a descending current. In such a situation there will inevitably be tips and bumps. Various combinations of such conditions as those here suggested explain "holes" and "pockets" and "bumps." [26]

A. General air movements essentially horizontal.

Layers.—The atmosphere, in spite of its being well mixed vertically, has more or less of a layer structure (stratification). Records of self-recording instruments sent up with ballons-sondes, and the courses of these ballons-sondes and of pilot balloons [27] have shown that these layers often differ considerably from one another in direction of movement; in velocity of movement; in temperature; in humidity; in cloudiness. Extended cloud sheets, for example, are often found in damp layers which have been cooled to their dewpoint, while above and below the sky may be cloudless. The rates of change of temperature vertically often vary a good deal in different air strata. It is when these rates are averaged that the rate of decrease of temperature of 1°F. in 300 feet, referred to in an earlier paragraph, is obtained. In flying, aviators thus often pass from one layer to another whose direction, or velocity, or both, may be different. A change in the adjustment of the machine becomes necessary. The machine may rise; it may fall slowly or rapidly as conditions may determine. Endless combinations are conceivable. No set rules can be given. Nor can the weather forecaster, from the daily weather map, tell definitely what the conditions of atmospheric stratification will be. Cloud observations help. Pilot balloons, when such are available, furnish the best means of determining the direction and the velocity of the higher air currents. Adjacent strata differing so greatly and so suddenly in direction and velocity from one another as to be dangerous, are rare. There is usually a gradual transition. Hence, if a strong current of air from one direction is above or below a strong current from an opposite direction, there is likely to be a layer of *comparatively* quiet air between. If difficulty is being experienced in any given layer, it should be remembered that the stratification is essentially horizontal, and a change of altitude will very likely bring better flying conditions. The maximum diversity between adjacent air strata occurs in connection with stormy weather, or when the weather is changing from fair to stormy.

Waves.—Friction between atmospheric strata moving over and differing from one another in density, direction, velocity, etc., often produces waves along the contact surface. These are essentially similar to the waves produced on water by wind. Balloons, traveling in such a wave layer, rise and fall with the waves. Von Helmholtz (1889) showed that atmospheric waves may have a length of hundreds of meters. When the moisture conditions are favorable, clouds form along the crests of these waves, while the troughs are unclouded or have thinner clouds in them. Under these circumstances, long parallel lines or rows of cloud are seen stretching across the sky. Sometimes these waves are only faintly developed, or appear in different parts of the sky. The lines of cloud may be continuous, or may be formed of separate small clouds, arranged in rows. The latter indicate a crossing of the layers, and the condition is similar to that of a "choppy sea," when long rollers are broken up into shorter and less regular waves by a change in the wind direction. Often a sheet of cloud is thrown into waves, the sky being wholly overcast, but the separate waves being distinguishable. Waves may occur at many altitudes. That atmospheric waves are often present when there are no clouds to indicate them is evident from the experience of aeronauts and of aviators, and from the records of delicate self-registering barometers, which at times show the passage, over the instruments, of regularly recurring oscillations of pressure. Flying along a wave level is apt to be "bumpy". If the machine is progressing against the waves, the irregularity of motion is greatest on account of the rapid changes in vertical motion. On the other hand, if the machine is flying with the wave motion, a smaller number of ascents and descents is experienced in the same interval of time. As the wave layer is an essentially horizontal stratum, relief can be secured by driving the machine up or down into a less disturbed region.

B. Local convectional currents, essentially vertical due to thermal controls.

Ascending currents are common on fine warm days, especially in summer. They are caused by the heating of the earth's surface under sunshine. The warmed air, being light, rises, as a cork rises through water. These rising currents are most common over mountains and hills, up whose slopes there are usually active ascending air movements during the warmer hours of fine summer days, and over open unforested areas. A freshly plowed field, of dark soil, is likely to be better warmed, and hence to be the seat of greater activity of ascending currents, than a field covered with crops or grass. When the warmed air rises high enough, and reaches its dewpoint temperature, the familiar fine-weather clouds of summer are formed, with their flat bases and bulging, convex tops (cumulus). These clouds are in many respects the most interesting from an aviator's point of view. They are "the visible tops of invisible ascending columns of air." As seen from above, "Cumulus clouds give the appearance of a very wild and rocky country; large cumuli resemble snow mountains."[28] They are naturally associated with more or less turbulent

[26] *Humphreys, William J.* Holes in the Air. Rept. Smithson. Instit. for 1912, pp. 257-268.

[A consideration of various types of air movements which the aviator is likely to meet. The classification is perhaps somewhat too detailed and the terms used, such as "aerial cataract," "breakers," "cascades," are likely to cause unnecessary alarm in a novice. The article is a suggestive one for the use of the teacher. The present writer has drawn on Prof. Humphreys' discussion in the paragraphs which immediately follow.]

[27] Pilot balloons are gas-filled spherical rubber or paper balloons of small diameter and without instrumental equipment. They are released for the purpose of determining direction and velocity of the upper currents, and have been followed to great distances and altitudes by means of special theodolites.—C. A. Jr.

[28] Lieut. Douglas Taylor, Royal Flying Corps.

("bumpy") conditions, of descending as well as of ascending currents. These conditions may extend to several thousand feet (10,000 feet more or less) above the surface. The base of cumulus clouds has a mean height above the surface of 4,600 feet (1,400 meters); while the tops average 5,900 feet (1,800 meters). Aviators report that "bumpy" conditions often occur on fine summer days even when there are no cumulus clouds. The explanation is that warm ascending currents are present, just as they are under cumulus clouds, but the rising air has not reached its dewpoint and hence remains clear. Probably, however, the most active ascending currents do not occur without cloud formation. It is easy to understand why fine, warm summer days, which would seem, at first thought, to give peculiarly steady flying conditions, are so "bumpy". Observations by means of kites and balloons have shown that the rate of ascent of the warm currents is often 10 to 12 feet per second. In thunderstorms this ascent is much more rapid.

All the air on a warm day can not be ascending. Descending currents are also inevitable. They may be met with in the clear space around the clouds; over the less easily warmed surfaces such as water, swamps, damp fields, and forests; and to some extent also intermingled with the rising movements. There is thus the difficulty of finding the machine tipping because it is partly in an ascending and partly in a descending current; or because it is between a rising or a descending current and the more or less quiescent air surrounding. Or, the aviator may run suddenly from an up current into a down current, and vice versa. Quick adjustments are often necessary. Under normal fine-weather conditions, however, such irregularities of air movements are not likely to be serious. It is well to remember that the turbulence of the lower air on a warm summer day is greatest during the warmer hours, and that the early morning and late afternoon hours are usually less cloudy and less "bumpy". During the warmer hours the surface wind also has a higher velocity, and is apt to be irregular and gusty, while the earlier and later hours are likely to be relatively calm. This is a practical point in connection with landing. The facts above noted about the surfaces over which there are apt to be the most active ascending, and those where there are likely to be descending movements, are also of practical value in flying. On clear, quiet nights, descending currents are likely down mountain slopes and in deep valleys, replacing the upslope currents of daytime.

Overcast days do not show the phenomena of local convectional air movements which have here been considered.

C. Effects of topography on air movements, combining both horizontal and vertical elements due to mechanical controls.

Wind near the ground is naturally variable and gusty. It is often forced to ascend or descend by the irregularities of the surface. Even where this surface is level, the lower air is retarded by friction and there is more or less descent of the faster-moving stratum just above. This results in a vertical interchange of air, of an irregular character. The extent to which such movements develop depends upon the amount of friction below and upon the relative velocity of the air currents. The surface wind is generally less gusty at night, hence this is as a rule the best time for flying. Sudden changes in the relation between the wind and the air currents just above the surface may be locally produced by alternating land and water surfaces, resulting in differing amounts of friction. Irregularities on the earth's surface cause many tangles, eddies, or waves in the moving air. Forests, buildings, all elevations or depressions, disturb the uniform flow of the lower air. In rising over an obstacle, such as a mountain range, or a hill, the air currents are likely to be congested, and their velocity increased. Winds are therefore usually stronger over mountain and hilltops, partly for this reason, and partly because of the faster movement of the upper currents. Again, when air rises over an obstruction such as an isolated hill, for example, it may be forced into a series of waves to leeward, and at the level of the hilltop. Such standing waves have been noted in the case of several mountains,[29] being sometimes visible because clouds form at the crests of the waves. There may be two or three successive waves, each one farther from the mountain top, and each one smaller than the last. These wavelike movements may cause temporary and local "bumps."

Prof. W. J. Humphreys, among others, has called attention most recently to the eddies which are likely to form on the leeward slopes of hills or mountains. The air comes down on the lee side in "cascadelike falls," which are more rapid the stronger the wind. Eddies are likely to develop close to the surface, the lower member of the eddy blowing up the slope, i. e., directly opposite to the general wind movement, which is downward. There are vertical down-currents on the down-slope, and vertical up-currents on the up-slope side of these eddies. The safe course is obviously to keep above the eddies and other irregularities of flow of the lower air. Eddies of this kind, combining both horizontal and vertical motions, are common close to the lee side of many obstructions; sometimes also, to a less degree, on the windward side. Aviators have many times reported active vertical currents in the lee of forests. In landing during strong winds, the close vicinity and especially the lee side of mountains, cliffs, hills, forests, in fact of obstructions of any kind, are likely to have disturbed wind movements. Decreased wind velocities will usually be found in sheltered localities, such as valleys transverse to the wind; as well as in forest clearings, where the wind is, however, likely to be very changeable, and to leeward of extended forests and of hills. In general, of course, by flying at greater heights, steadier winds will be found. The effect of surface irregularities upon the winds aloft is more marked, and extends farther, the greater the wind velocity.

CLOUDS.

Clouds are among the aviator's most serious meteorological handicaps, but they have two very practical uses: (1) They show the direction of the higher air currents, and (2) they are useful as weather prognostics. Accurate determination of cloud movements requires the use of a nephoscope and of a theodolite,[30] but somewhat rough but fairly satisfactory observations may be made noninstrumentally. A cloud patch, or some easily identifiable point in a cloud sheet, near the zenith, should be brought in line with the corner of the roof of a building, with the end of a branch of a tree, or with

[29] Green Mountain, on the island of Ascension, for example, as reported by the late Prof. Cleveland Abbe.

[30] *Abbe, Cleveland:* Treatise on Meteorological Apparatus and Methods. Ann. rept., Chief Signal Officer for 1887, Appendix 46. Washington, D. C., 1888.

Clayton, H. H., Discussion of the cloud observations made at Blue Hill Observatory, Mass., U. S. A. Ann., Astron. obsy. Harv. Coll., v. 30, pt. IV, 1896. Cambridge, Mass., 1896, 4°. pp. 273–278.

some other fixed object. As the cloud moves, the compass direction of its movement can roughly be determined. To have even such crude observations as these of value, some knowledge of cloud heights is necessary,[31] so that it may be clear at what altitudes the various wind directions, indicated by the observed cloud movements, will be encountered. Sometimes cloud directions for two or three different levels may be determined at the same time. The lower clouds, being nearer, seem to move faster, while the upper clouds, although actually traveling at greater velocities, apparently move much more slowly. It is impossible, therefore, without instrumental observation, to gain anything more than an indefinite, and sometimes indeed even a misleading, idea of the velocity of the upper currents. Cloud perspective also is a puzzling matter, but practice in watching cloud movements will soon enable anyone to make fairly accurate observations.[32]

A careful study of clouds as weather prognostics involves a long period of discriminating individual local observation and record. A few very general suggestions are here made. Further information may easily be secured by those who desire it.[33] Detached, scattered, isolated clouds are as a whole characteristic of fine weather. When, however, they become more numerous, spreading over the sky; when they arrange themselves in long parallel rows, giving the appearance of waves, and when they are followed by sheets of cloud, wet and perhaps stormy weather is indicated. Cloud sheets gradually spreading from the western horizon across the sky toward the east; becoming lower and darker; with rings (haloes, coronæ) around sun or moon; or with a "wet" moon and a "watery" sun, are storm prognostics.[34] *Wave* sheet clouds are still better rain prognostics. Even the general path of a storm with reference to the observer can often be foretold by cloud observation. For example, if thickening "mare's tail" cirri are seen diverging from the west or southwest they may serve as indications of a storm approaching from that quarter, which, as it moves eastward, is likely to affect the weather at the observer's station. On the other hand, when such clouds are seen diverging from the north, the storm is probably passing by to the eastward too far away to control the local weather.

Fog and low cloud sheets are very unfavorable for the aerial observer. They either make observation altogether impossible, as in the case of a fog, or they oblige him to fly so low, beneath the cloud, that he is within close range of the anti-aircraft guns; as in the case of stratus and nimbus clouds.[35] Isolated, detached clouds, on the other hand, may interfere with reconnaissance work, but do not stop it altogether. The clouds here selected for brief discussion from a practical point of view, are those which are most critical for the aviator. They are fog (not classed as a cloud by meteorologists), the lower sheet clouds, and the thunderstorm cloud.

Fog.—Typical land fog, which is the kind of fog that most frequently affects flying, occurs when there is little or no wind; under clear skies; chiefly on autumn and winter nights, although it is frequent throughout the year. In summer it usually "burns off" soon after sunrise; in the colder months it may last all day. This is a point worth remembering by aviators. The thickness of a fog sheet varies greatly according to conditions of weather and of topography. It may be only a few feet; it may be several hundred feet in a mountainous country. Typical land fogs form first and are thickest in the valleys and on lowlands. Hence they are often called valley and lowland fogs. When flying above a thick, widespread, dense fog sheet, it is impossible to see the surface. Hence it is essential that the distance above the ground should be known within very close limits. These fogs are favored by high pressures, because then the sky is apt to be clear and the wind light. Apart from the fog, the flying conditions are very favorable. The lower air is then very stable.[36] Fogs are formed in other ways, also, as in the case of damp winds blowing in from the sea (marine fog conditions), or when the mixture of different air currents leads to condensation. Such fogs may last for days. Coast fogs are generally more frequent in summer, while typical land fogs are more characteristic of fall and winter.

Lower sheet clouds.—At an altitude averaging less than 3,500 feet above the surface, but often reaching nearer, there is a high fog (*stratus*) whose relations to flying are much the same as those of ordinary fog. In fact stratus cloud is essentially, as its definitions puts it, "lifted fog in a horizontal stratum." It is, however, usually much thicker than an ordinary fog; does not rest on the ground, and lasts longer. It may be a typical fog which has been actually lifted from the ground, or it may have formed by mixture or by condensation between cool and warm air currents. There are, in fact, all gradations between fog and stratus cloud. It is common in winter, at night, and in higher latitudes. Although often mistaken for a rain cloud, stratus does not give precipitation, but it may precede rain or snow. Its vertical thickness varies greatly, and may reach a few hundreds of feet. It does not "burn off" as typical land fog usually does, and may persist for several days. Seen from above, stratus presents the appearance of a "sea of clouds." Its top may be very even, or may be in waves or billows. Reconnaissance work is practically impossible, but stratus is not a storm cloud and flying *above* it presents no special meteorological difficulties. Orientation is, of course, difficult or impossible. If the cloud sheet is not too thick, the upper surface of it, under certain favorable conditions, indicates the topography beneath, rivers and valleys appearing as depressions and mountains as elevations. This is a practical point worth remembering. Many aviators have been able to get their bearings in just this way. The temperature often increases for a time with ascent above the earth's surface when stratus clouds are present.

The ordinary rain cloud (*nimbus*) is another low sheet cloud which is likely to prevent aerial reconnaissance. This is the familiar low, dark blue, structureless cloud from which rain or snow usually falls, and below which broken irregular fragments of "scud" often drift. The base of the rain-cloud varies a good deal in height above the earth's surface. It averages under 6,500 feet (International Cloud Classification), and may be much lower. The Blue Hill results give its most frequent altitude as 2,000 feet. Of its vertical thickness little is definitely known. That it does not extend to great heights is clear from the fact that when openings occur in it, or when an

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[31] *See* Atlas International des Nuages; *also* Illustrative Cloud Forms for the Guidance of Observers in the Classification of Clouds, by U. S. Hydrographic Office; *also* recent textbooks.

[32] A simple discussion will be found in *Ralph Abercromby:* Weather, 1887, pp. 87–92.

[33] See *H. H. Clayton*, loc. cit.; also *W. J. Humphreys*, Some weather proverbs and their justification, Pop. sci. mo., New York, May, 1911, pp. 428–444.

[34] At Blue Hill, Mass., cirro-stratus usually precedes rain by about 13 hours; alto-stratus, by about 6 hours.

[35] The complete classification of clouds, with illustrations and descriptive text, will be found in the "Atlas international des nuages" and in "Illustrative cloud forms for the guidance of observers in the classification of clouds," U. S. Hydrographic Office.

[36] See an important paper by Maj. *G. I. Taylor*, R. F. C.: The formation of fog and mist. Quart. journ., Roy met. soc., July 1917, 43: 241–268.

aeroplane flies up through it, higher clouds at elevations of 2 to 3 and up to 5 or 6 miles are often to be seen.[37] Aeronauts and aviators have frequently passed through and above the nimbus at an altitude between 6,000 and 7,000 feet. The duration of the rain cloud depends on the size, development, and rate of progression of the general storm (low pressure) conditions with which it is associated. It may last a few hours. It may, especially in winter, cover the sky for 2 or 3 days. A rising barometer and a change in wind are the usual indications of clearing, from the rain cloud to the broken clouds which follow a storm. Fog, elevated fog (*stratus*), and the ordinary rain cloud are thus all of them serious handicaps in aerial reconnaissance, because they are on or near the surface, and conceal that surface very effectively from above.

There is another sheet cloud, at a considerably greater height, which may be described. This is the more or less uniform sheet of bluish cloud, distinctly higher than the rain cloud[38] through which the sun or moon may be seen faintly, as through ground glass (*alto-stratus*).[39] This cloud usually precedes a general rain by a few hours.[40] It is not itself a rain cloud, but is associated with coming wet weather.

Thunderstorm cloud.—There are only two cloud types which ordinarily bring precipitation. These are the general rain cloud (*nimbus*) and the thunderstorm cloud (*cumulo-nimbus*). The former gives the persistent rains or snows of a general storm. The latter gives the shorter, usually heavier, and often squally rains (including hail) or snows. Of this type the summer thunderstorm is the obvious example.[41]

In view of its importance to the aviator, the thunderstorm cloud requires further mention. In a previous section (see p. 595) reference was made to the ordinary summer daytime cloud (*cumulus*) produced by local ascending warm currents. Aviators know well that under these conditions there is always more or less turbulence, which causes "bumps" in flying. These irregularities of ascending, descending and gently whirling air currents usually offer no serious difficulties. Often, however, the cumulus develops into a thunderstorm cloud (*cumulo-nimbus*), and then all these atmospheric movements are greatly accentuated. The cloud mass becomes extremely turbulent; the velocity of the ascending and descending currents increases; the heavy downpour of rain, perhaps mixed with hail, and the danger arising from the lightning, add to the difficulties. Vertical currents in thunderstorms may sometimes attain a velocity comparable with that of strong surface winds (Sir N. Shaw). In addition to receiving all possible assistance from the official weather forecast, the aviator should know how to predict the occurrence of local thunderstorms. He should, also, know enough about the characteristics of thunderstorms to be able to manage his machine to the best advantage in case he has to fly in one of them.

The typical thunderstorm cloud is an overgrown and greatly developed cumulus cloud. Its base is about three-fourths to 1 mile above the earth's surface, but is usually concealed by the falling rain. Its top varies from somewhat over a mile to 5 miles in extreme cases.[42] The thunderstorm type of cumulus has massive, hard rounded tops (thunderheads). The upper edges of these bulging tops very often, especially in the more severe thunderstorms, seem to become soft, and brushed out into a sheet or screen more or less fibrous and raveled (*false cirrus*), which gives the whole cloud, when seen from the side, the shape of an anvil. Or, the upper edges may remain hard and convex, like ordinary cumulus, while the delicate sheet of false cirrus floats around them. When, on a warm, muggy, summer day ordinary cumulus clouds are seen to be increasing in height, growing darker, joining, and especially when the screen or veil of false cirrus forms, local thunderstorms are likely to occur. Further, when a rising mass of cumulus is seen to develop a ring or "collar" just below its top, caution is advisable. When, on the other hand, cumulus clouds break up, flatten and spread, and do not attain great height, the signs are favorable. The extraordinarily rapid upward growth of many cumulus and especially cumulo-nimbus clouds is due, at least partly, to the accumulation of the warm air below until it is able to break up through the overlying more stable strata. When once started, the warm air goes up with a rush, and the cloud may grow thousands of feet vertically in a very short time.

It is much the safer course for an aviator not to fly in a thunderstorm. But if he finds himself in the air when a thunderstorm is approaching, what shall he do? The meteorologist can give him a few suggestions. Thunderstorms in Europe, as well as in the United States, move in a generally easterly direction, at hourly velocities of 20 to 50 miles in the United States, and somewhat less in Europe. At any one time the storm itself has more or less of the shape of a convex lens, the convex side being on the front. The distance through the storm, from front to rear, is small, often less than 50 miles. Many of these storms are so small that it is perfectly easy to fly around them, on their northern or southern margins. On the other hand, the more extended ones, often called "line thunderstorms," may have a front extending roughly north and south for several hundred miles. An aviator can easily fly away from an advancing thunderstorm if such a course will not bring him into the enemy lines. He can also fly over the top of many of the smaller storms, and even over such of the larger ones as have not an excessive vertical development. If the top of the storm is so high that he can not fly over it, and no other course is open, the aviator should steer directly through the upper part of the cloud, facing the advancing storm. Usually a few minutes will bring the machine out into the rear of the storm. Thunderstorms are of many types and of many sizes and degrees of intensity. Hence it is quite impossible to frame rules which will meet every emergency. The possible damage to propellers or to wings resulting from large hailstones is considerably reduced by the fact that hail occurs over limited areas only and that many thunderstorms produce no hail.

It may be noted that airplanes can and do travel above the levels of many weather conditions (e. g., heavy rain or snow), which might be rather serious handicaps nearer the surface.

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[37] E. g., alto-stratus, cirro-cumulus, cirro-stratus, alto-cumulus.

[38] The highest cloud sheet is the thin, delicate, milky, sometimes net-like *cirro-stratus*; formed of ice crystals; often producing haloes, and usually the first sheet cloud seen in front of an approaching storm. As the height of this cloud is between 5½ and 6 miles, it is beyond flying levels. At about 1 mile above the surface a grey cloud, of long rolls, usually covering the sky, often gives the appearance of a sheet but is, in reality, a broken cloud layer with lighter or open spaces between the separate rolls. This cloud (*strato-cumulus*) is common in quiet winter weather, and may persist for days. It makes the day dull and gloomy, and suggests snow or rain, but it is not a rain cloud. From above it has the appearance of "a gently undulating country".

[39] This belongs in the "intermediate" level, between 10,000 and 23,000 feet and averages about 3 miles above the surface.

[40] At Blue Hill Observatory rain follows *alto-stratus* in about 6 hours.

[41] Brief transient showers may, far less frequently, fall from two or three other cloud types, e. g., *strato-cumulus*.

[42] *Lieut. C. K. M. Douglas*, R. F. C., estimates that a height 6,000 feet from top to bottom is an absolute minimum at which cumulus clouds may develop into thunderstorms. On all occasions on which thunder occurred in France in 1916 the height of the cloud from top to bottom was not less than 10,000 feet. (*Journ., Scot. met. soc.* 3d ser., No. 33, 1916, 17: 65-73; *or* MONTHLY WEATHER REVIEW, Washington, March, 1917, 45: 93.)

WEATHER FORECASTING.

Surface conditions.

Whether in peace or in modern war the aviator usually has access to the official daily weather forecasts. He is not concerned with the collection of the meteorological data, with their charting, nor with the making of the forecasts. He should, however, understand, in a general way, the broad principles upon which modern weather forecasting depends. He should know how to interpret a weather map for himself. He should be able to make his own individual rough noninstrumental forecast, so that he may be able to fill in the gaps between the hours at which the official forecasts are made, and may not, if out of reach of an organized meteorological service, be perfectly helpless about probable coming weather conditions.

So far as the United States map is concerned, the information can easily be secured.[43] The British maps use millibars (see p. 593) and Absolute temperatures [32°F. = 0°C. = 273°A] instead of inches and hundredths and Fahrenheit degrees. The French maps use millimeters and centigrade degrees. Some idea of European weather types would be a most important and helpful addition to the meteorological knowledge of any aviator whose duty calls him to service in Europe. This subject has received a great deal of attention on the part of European meteorologists, and may be looked up without much difficulty.[44] The individual who makes his own noninstrumental local weather forecasts, without the help of a weather map, is in the primitive stage of forecasting. He must depend entirely upon weather signs or prognostics. The indications afforded by the systematic changes in direction and velocity of the wind [45] are usually the best guides. The aviator being especially concerned with the clouds and high winds which are commonly associated with cyclonic storms, will find it well to watch the wind carefully. "Backing winds," from easterly through north to westerly, indicate the approach and passage of a low pressure area on the south. "Veering winds," from easterly through south to westerly, indicate the approach and passage of an area of low pressure on the north. If a barometer is available, the barometric tendency, i. e., the rise or fall and the rate of rise or fall, should be constantly noted. In general, the approach and occurrence of foul weather are associated with a falling and a low barometer, and of fair weather with a rising and a high barometer.[46] Changes in wind direction mean changes in the distribution of pressure; i. e., in the location of the isobars and hence of the centers of high and low pressure. Changes in wind velocity alone, on the other hand, mean changes in the barometric pressure or pressure gradient, i. e., they mean that the distances between the isobars are increasing or decreasing. In addition to these indications, cloud prognostics, as above suggested, are very useful, and there are many good weather proverbs which, if rightly applied, are helpful.[47]

Forecasts of wind direction and velocity aloft.

The ordinary forecasts relate only to surface conditions. For the aviator, some idea of the probable wind aloft is obviously also important. Direct observation by means of small pilot balloons, whose course can be followed by means of theodolites, gives excellent indication of the direction and velocity of the upper currents up to ordinary flying heights. This method involves instruments and a certain amount of mathematical calculation, and must therefore be left to the trained meteorologists. Kites have also been used in this work. In the present war the Germans have evidently made extended use of pilot balloons electrically lighted at night. Direct observation of cloud movements also serves to give definite information of upper air currents. Here again, beyond the simple noninstrumental cloud observations above referred to, the trained meteorologist must be relied on to make use of his nephoscope and his theodolite, and to work out his results.

We come, then, to the already ascertained facts which may be of service in inferring the winds aloft. First, as to direction. For the first few thousand feet up (roughly, perhaps, 4,000–5,000 feet) the direction of the wind usually changes to the right, i. e., in a clockwise direction from that of the wind at the surface. Thus, if the wind at the surface is SW., the wind aloft may be expected to be more westerly; if the surface wind is N., the direction aloft is likely to be more from NE. With increasing distance from the surface, and decreasing frictional resistances, the winds tend more and more to follow the isobars.[48] This condition may be reached at about 1,500 feet, more or less, varying according to circumstances. In fact, different weather types and conditions exert so many varying controls that no hard and fast rule can be laid down. In general, however, it may be said that the shift in wind direction to the right is most marked near the beginning of an ascent, and up to 4,000–5,000 feet the winds may be expected to blow more or less along the isobar. At greater altitudes, above the influence of the surface gradients, the winds tend to come more and more from westerly directions, and easterly directions become less and less frequent.[49] The higher the flight, the greater will be the tendency of the air currents to blow from a westerly point. This is true in Europe as well as in the United States.

On fine, warm days, especially in summer, the lower air and the air somewhat above the surface tend to intermingle as the result of more or less vertical movement. The descending air currents bring down their own directions, and therefore there is a tendency for the surface wind directions to veer to the right during the day. At night, the tendency is to swing back again. This is known in meteorology as the *diurnal variation in wind direction*. In extremely favorable conditions, the shift may be as much as 90°. In the case of a prolonged flight, it must be remembered that the directions of both surface winds and upper currents are likely to be affected by the progression of the isobaric system as a whole.

Secondly, as to the velocity of the air currents aloft. On the average, this velocity increases with increasing altitude, up to the level of the highest clouds. Thus, from measurements of clouds, made at Blue Hill Observatory, Upsala (Sweden), and Potsdam (Germany), for example, the mean velocities of air movements at various levels are as follows:

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[43] *See* The Weather Map and its Explanation; and Wind-Barometer Indications, both published by the U. S. Weather Bureau, Washington, D. C.

[44] See, e. g., *W. J. van Bebber:* Lehrbuch der Meteorologie, 1890, pp. 317–343. Also: *J. G. Bartholomew*, Atlas of Meteorology, Edinburgh, [189?]. Plate 32, Text p. 35.

[45] Especially if supplemented by readings of a barometer.

[46] For the United States, the "Wind-Barometer Table" (see footnote [43]), gives the weather indications associated with various barometer readings and tendencies, combined with accompanying wind changes.

[47] *W. J. Humphreys:* "Some weather proverbs and their justification," Pop. sci. mo., May, 1911, pp. 428–444.

[48] This is known as the "gradient wind direction."

[49] In this connection the results regarding wind movements at all heights in cyclones and anticyclones obtained at Blue Hill Observatory are very important. See *H. H. Clayton.*—Discussion of the cloud observations made at the Blue Hill Observatory, Mass., U. S. A., *Annals Astron. Obsy. Harv. Col.*, Vol. XXX, Pt. IV, pp. 437–449.

See also chart 21 (Winds at Various Heights as Related to Barometric Pressure at the Ground) in *A. Lawrence Rotch & Andrew H. Palmer.*—Charts of the atmosphere for aeronauts and aviators.

For a summary of European results see *J. von Hann.*—Lehrbuch der Meteorologie, 3d ed., 1915, pp. 52?–5?6, 54?–545. In the United States, as shown by F. H. Bigelow and H. H. Clayton, and in central Europe, as shown by Åkerblom, the low and high pressure areas of the earth's surface have comparatively little influence on the upper currents in the cirrus level.

Mean cloud velocities at different heights.

Levels.	1,600–6,500 feet.	6,500–13,000 feet.	13,000–20,000 feet.
	Mis./hr.	*Mis./hr.*	*Mis./hr.*
Upsala	20.4	19.5	35.8
Potsdam	20.8	23.0	37.8
Blue Hill	21.9	31.8	38.3

Two points may be noted in this connection. Cloud velocities can not be considered as giving accurate indications of air movement because (1) certain cloud types are commonly associated with certain special weather types, and because (2) the upper clouds can only be seen when not obscured by lower clouds. Further, for the aviator, mean velocities are much less critical than gustiness. The above table shows that there is an average increase in velocity from about 20 mis./hr. below a height of a little over 1 mile, to 35 to 40 mis./hr. at 13,000 to 20,000 feet. While the average velocity thus increases aloft, the gustiness usually decreases. Roughly, in the lower 1,000 to 2,000 feet the velocity may be expected to increase "as the height above sealevel." If, e. g., there is a wind of 15 mis./hr. at 500 feet above sealevel, a wind of 30 mis./hr. may be expected 1,000 feet above sealevel, and one of 45 mis./hr. at 1,500 feet. Finally, certain calculations which the aviator is not likely to have the time or opportunity to make for himself make it possible to predict, usually with reasonable accuracy, the wind velocities at about 1,500 feet, and up to, say, 3,000 to 4,000 or 5,000 feet.[50] At and near the earth's surface friction is a large and uncertain element in the problem. But at about 1,500 feet above the surface the effect of surface friction is slight. If the pressure gradient[51] be known, the "gradient-wind velocity" may be determined. This is the ideal wind, calculated from the gradient. It is the air movement needed to balance the pressure gradient. It also depends upon the density of the air, that is upon the temperature and pressure, and upon latitude. Tables have been prepared showing the gradient-wind velocities under varying conditions and at various latitudes.[52] The calculated results agree fairly closely with the results of observations made by means of kites and balloons. The complete formula is somewhat complicated, but a simple working basis is contained in the following table, adapted from one given by Prof. W. J. Humphreys.[53]

Table for calculating gradient-wind velocity.

Lat.	*Mis./hr.*
40°	$\frac{1900}{M}\times 2.24$,
50°	$\frac{1600}{M}\times 2.24$,
60°	$\frac{1400}{M}\times 2.24$.

M=number of miles between isobars.[54]

In the foregoing calculation it is assumed that the pressure gradient at 1,500 feet is the same as that at the earth's surface, as shown on the weather map. If we had isobaric maps for greater altitudes, the winds at those heights could be predicted. It is known that the arrangement of the isobars, and also the pressure gradients, change fairly rapidly with increasing elevation. For this reason, predictions of gradient-wind velocity (and direction) can not be absolutely relied on, and are limited to the lower few thousand (below 5,000) feet.[55] No definite rules can be laid down. Above the height at which the gradient velocity is reached, very diverse conditions are met. The velocity may increase. It may decrease. Indeed, the gradient velocity itself is not always reached. There is also a curious uncertainty about easterly winds. While westerly winds usually reach their gradient velocities at 1,500 feet or so, and then, as a whole, increase still further up to the maximum flying heights, easterly winds are very erratic both in changes of direction and of velocity. They do not show the same tendency to give gradient velocities. While westerly winds usually blow stronger at higher levels, easterly winds often decrease in velocity aloft, being then replaced by westerly winds. Easterly winds should therefore be carefully watched.[56]

On fine, warm summer days the surface wind very commonly blows strongest during the warmer hours, while the mornings, evenings, and nights are calm. This is known as the *diurnal variation in wind velocity.* It does not occur on cloudy or stormy days. Obviously, it is to be reckoned with in making a landing. Somewhat above the surface the variation in velocity is just the opposite. During the warmer hours, when the surface winds are blowing hardest, the air currents somewhat above the surface are slackened. At night, when the surface winds die down, the movement is more rapid aloft. The height to which this condition reaches depends on general weather conditions. When conditions are favorable, on hot summer days, it may reach nearly a mile. On such days, therefore, the aviator may find the wind velocity decreasing for a time as he ascends.

FAVORABLE AND UNFAVORABLE WEATHER FOR FLYING.

Summarizing briefly, high-pressure conditions are, on the whole, the most, and low-pressure conditions the least, favorable for flying.

High pressures as a rule have the advantage of lighter winds; of high and detached clouds; of fine weather. They have the disadvantage of being favorable to the formation of fog and of low stratus clouds, especially in winter, and during prolonged dry spells in summer a ground haze, which interferes with reconnaissance work, is common. High-pressure spells in summer are also apt to be times of active ascending diurnal currents, hence of "bumpy" conditions. The diurnal increase in wind velocity and the diurnal variation in wind direction are also best marked at such times.

Low pressures, on the other hand, are usually accompanied by general cloud sheets; by rain or snow; often by high winds, especially in winter. They thus bring conditions which may make flying difficult, ineffective, even impossible.

[50] It is perfectly feasible for the official forecasters to include the direction and velocity of the wind at 1,500 feet in their regular daily forecasts of surface conditions. They have been doing this abroad.

[51] The distance from one isobar to the next lower isobar, measured as nearly as possible at right angles to the two.

[52] *Great Britain. Advisory comm. aeronaut.* Report No. 9.
Great Britain. Meteorol. Office. Computer's Handbook, Sect. II. (M. O., No. 223).
Gold, Ernest. Barometric gradient and wind force. (Metl. O., No. 190.)

[53] In Prof. Humphreys' original paper (Jour. Franklin Instit., Phila., March, 1913, p. 234) the values are given for meters second. The heading over his last column should read "Meters per second," not "Miles per hour."

[54] Formula as given by Dr. John Patterson, Meteorological Office, Toronto:

Lat.	*Mis./hr.*
40°	$\frac{3908}{M}$,
50°	$\frac{3279}{M}$,
60°	$\frac{2900}{M}$.

[55] Expected changes in surface pressure gradients are, to a considerable extent, predictable by the official forecasters.

[56] In England *Capt. C. J. P. Cave* has shown that different types of wind velocity distribution in the atmosphere prevail under different conditions. Thus, he has found cases when (1) the velocity remains steady even up to several thousand feet, (2) the velocity increases with height (usual condition), (3) the velocity decreases and then increases, (4) the velocity increases and then decreases.